PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference PE-0657	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/BR 02/00174	International filing date *(day/month/year)* 05.12.2002	Priority date *(day/month/year)* 05.12.2002

International Patent Classification (IPC) or both national classification and IPC
H04B10/17

Applicant
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1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 9 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the opinion

   II ☐ Priority

   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

   IV ☐ Lack of unity of invention

   V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

   VI ☐ Certain documents cited

   VII ☐ Certain defects in the international application

   VIII ☐ Certain observations on the international application

Date of submission of the demand 28.04.2004	Date of completion of this report 08.04.2005
Name and mailing address of the International preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Shaalan, M Telephone No. +49 89 2399-7723

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.   PCT/BR 02/00174

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, Pages

1, 2, 5-18	as originally filed
3, 4, 4a	received on 25.10.2004 with letter of 25.10.2004

Claims, Numbers

1-25	received on 25.10.2004 with letter of 25.10.2004

Drawings, Sheets

1/7-7/7	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).

   ☐ the language of publication of the international application (under Rule 48.3(b)).

   ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   ☐ contained in the international application in written form.

   ☐ filed together with the international application in computer readable form.

   ☐ furnished subsequently to this Authority in written form.

   ☐ furnished subsequently to this Authority in computer readable form.

   ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description,   pages:

   ☐ the claims,   Nos.:

   ☐ the drawings,   sheets:

Form PCT/IPEA/409 (January 2004)

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)).

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-25
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-25
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-25
	No:	Claims	

2. Citations and explanations

   see separate sheet

Re Item V
Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1.   Reference is made to the following documents:

      D1:   EP-A-0883218
      D2:   US-A-6052218
      D3:   US-B1-6317254
      D4:   EP-A-0617527

2.1   Document D1, see in particular the passages cited in the search report, discloses as in claim 20 (the references in parenthesis apply to the figures of D1):

a method for optical amplifying comprising the steps of:

directing the optical signals within a first wavelength interval to a first nonlinear optical fibre (250-221);

directing the optical signals within a second wavelength interval to a second nonlinear optical amplifier (250 - 227);

performing first amplification in said first nonlinear optical fibre, by pumping with radiation of a first pump wavelength (245);

performing second amplification in said second nonlinear optical fibre, by pumping with radiation of a second pump wavelength (246);

said first pump wavelength being positioned outside said first wavelength interval and said second pump wavelength being positioned outside said second wavelength interval; and

multiplexing amplified signals from said first and second nonlinear optical fibres from which the subject-matter of claim 20 differs in that

the amplification is performed by parametric amplification.

2.2   The problem to be solved by the present invention may therefore be regarded as "which optical amplification mechanism to select in order to improve the reduce crosstalk"

2.3   The solution proposed in claim 20 of the present application is considered as involving an inventive step (Article 33(3) PCT) for the following reasons.

None of the documents hint at using a parametric amplifier in a split band structure. The parametric amplifier uses a different idler frequencies in each branch, thereby causing less crosstalk. Since there is a particular advantage in using parametric amplifiers in order to solve the problem solved, namely to reduce crosstalk, the claim is considered as inventive.

3.   The subject-matter of independent claims 1 and 17 corresponds to the subject-matter of claim 20, therefore the above argumentation applies mutatis mutandis.

attracted interest because the band of amplification depends on the design of the fiber used and thus can be moved outside the conventional rare-earth window band. This will allow the use of the full low-loss window of fused silica fiber. Fiber optical parametric amplifiers are able to operate in any of the telecommunication bands (S-C-L) depending upon pump wavelength and the fiber zero dispersion wavelength, which can in principle be appropriately tailored from 1300 nm to 1600 nm.

A fiber optical parametric amplifier operates based on the nonlinear process of wave mixing, whereby a pump source at a given wavelength close to the zero dispersion wavelength of an optical fiber leads to the generation of idler and signal bands from spontaneous noise. If an externally injected signal is simultaneously applied, it can be amplified in any of the signal or idler band, which are basically symmetrically located with respect to the pump wavelength.

Fiber optical parametric amplifiers are conventionally known for having a low efficiency, which means that very high laser pump power would be needed. The gain of a fiber optical parametric amplifier depends in general on three parameters; the nonlinear coefficient γ, the length L of the fiber used as amplification medium and pump power P_P. A low nonlinear coefficient calls for use of a high pump power or a long fiber length. However, recently, optical fibers having higher nonlinear coefficients have been even commercially available.

US 6,052,218 discloses a high brightness optical parametric amplifier array, using energy-scalable optical parametric amplifiers that provides high brightness output. The scaleability in energy is achieved by using an array of

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parallel crystal amplifiers to handle high laser energies. High brightness is obtained by using an optical phase conjugator to keep the phase front of the array coherent.

5   A relatively large problem with fiber optical parametric amplifiers is that the amplification principle gives rise to crosstalk. Optical signals having one wavelength will during the amplification process give rise to "false" signals at other wavelengths due to Four-Wave mixing (FWM). In DWDM systems, such crosstalk can generally not be accepted.

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RELATED ART

In US 6,239,903 fiber optical parametric amplifiers are used in series with Raman amplifiers in order to widen the amplification gain. A similar approach

15   is shown in M. C. Ho, K. Uesaka, M. E. Marhic, Y. Akasaka and L. G. Kazovsky, "200-nm-Bandwidth Fiber Optical Amplifier Combined Parametric and Raman Gain", IEEE J. Lightwave Technol. 19, 977-979 (2001). In US 6,049,417 (equivalent to EP 0 883 218) parallel sub-bands are amplified by use of different types of rare-earth optical amplifiers. In US 6,317,254, a parallel

20   optical fiber amplifier is disclosed having a parallel EDFA configuration in which reverse ASE is reused as a secondary pumping source. In US 5,452,116, parallel optical sub-band amplifiers are used in series with single full-band amplifiers to compensate for uneven gain characteristics. In J. Hansryd and P. A. Andrekson, "Broad-band continuous-wave-pumped fiber optical parametric

25   amplifier with 49-dB gain and wavelength-conversion efficiency", IEEE Photon. Technol. Lett. 13, 194-196 (2001) multi-segment fiber design is used to achieve a relative large bandwidth and high gain parametric amplifiers. Dual pump schemes have also been employed, see e.g. C. J. McKinstrie, S. Radic and A. R. Chraplyvy,

→ 4a

4a

"Parametric amplifiers driven by two pump waves", IEEE Select. Topics Quantum Electron. 8, 538-547 (2002).

SUMMARY

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One common problem with parametric amplifier solutions according to prior-art is according to previous discussions potential crosstalk from four-wave mixing products. Moreover, there is a general lack of flatness of the available gain bandwidth, calling for extra flattening devices. Furthermore, an increased

10　　bandwidth is also generally requested.

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CLAIMS

1.   Optical amplifier device (1) comprising:

optical input (10);

5   a first nonlinear optical fiber (12A-C), having a first set of fiber property parameters, comprising a first zero-dispersion wavelength (λ_0);

a second nonlinear optical fiber (12A-C), having a second set of fiber property parameters, comprising a second zero-dispersion wavelength (λ_0);

optical demultiplexer (14) connecting said optical input (10) and said
10   first and second nonlinear optical fibers (12A-C), directing optical signals within a first wavelength interval ($\Delta\lambda_1-\Delta\lambda_8$) to said first nonlinear optical fiber (12A-C) and directing optical signals within a second wavelength interval ($\Delta\lambda_1-\Delta\lambda_8$) to said second nonlinear optical fiber (12A-C);

at least one optical pump (18; 18A-C), pumping said first and second
15   nonlinear optical fibers (12A-C) with radiation having a pump wavelength (λ_P) in the vicinity of respective said zero-dispersion wavelength (λ_0);

said first nonlinear optical fiber (12A-C) giving a high parametric amplification in said first wavelength interval ($\Delta\lambda_1-\Delta\lambda_8$) and said second nonlinear optical fiber (12A-C) giving a high parametric amplification in said
20   second wavelength interval ($\Delta\lambda_1-\Delta\lambda_8$);

optical output (20); and

optical multiplexer (16) connecting said first and second nonlinear optical fibers (12A-C) and said optical output (20), merging optical signals from said first and second nonlinear optical fibers (12A-C) into said optical output
25   (20);

a pump wavelength (λ_P) provided to said first nonlinear optical fiber (12A-C) being positioned outside said first wavelength interval ($\Delta\lambda_1-\Delta\lambda_8$) and a pump wavelength (λ_P) provided to said second nonlinear optical fiber (12A-C) being positioned outside said second wavelength interval ($\Delta\lambda_1-\Delta\lambda_8$).

2.   Optical amplifier device according to claim 1, **characterized in that** said first wavelength interval $(\Delta\lambda_1 - \Delta\lambda_8)$ being positioned at a high-gain portion of a gain distribution (100; 120, 122, 124; 126, 128, 130; 132, 134) of said parametric amplification in said first nonlinear optical fiber (12A-C), and said second wavelength interval $(\Delta\lambda_1 - \Delta\lambda_8)$ being positioned at a high-gain portion of a gain distribution (100; 120, 122, 124; 126, 128, 130; 132, 134) of said parametric amplification in said second nonlinear optical fiber (12A-C).

3.   Optical amplifier device according to claim 1 or 2, **characterized in that** said first set of fiber property parameters is different from said second set of fiber property parameters.

4.   Optical amplifier device according to any of the claims 1 to 3, **characterized in that** said first nonlinear optical fiber (12A-C) and said second nonlinear optical fiber (12A-C) are pumped with one common optical pump (18), whereby said first and second nonlinear optical fibers (12A-C) are pumped with the same pump wavelength (λ_P).

5.   Optical amplifier device according to claim 4, **characterized in that** said first nonlinear optical fiber (12A-B) has a second order dispersion coefficient β_2 different from the second order dispersion coefficient β_2 of said second nonlinear optical fiber (12A-C).

6.   Optical amplifier device according to any of the claims 1 to 3, **characterized in that** said first nonlinear optical fiber (12A-C) is pumped with a first optical pump (18A-C) and said second nonlinear optical fiber (12A-C) is pumped with a second optical pump (18A-C).

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7. Optical amplifier device according to claim 6, **characterized in that** said first optical pump (18A-C) has a pump frequency different from the pump frequency of said second optical pump (18A-C).

5 8. Optical amplifier device according to claim 7, **characterized in that** said first and second nonlinear optical fibers (12A-C) substantially have the same second order dispersion coefficients β_2.

9. Optical amplifier device according to any of the claims 3 to 8,
10 **characterized in that** said first nonlinear optical fiber (12A-C) has a zero dispersion wavelength (λ_0) different from the zero dispersion (λ_0) wavelength of said second nonlinear optical fiber (12A-C).

10. Optical amplifier device according to claim 1, **characterized in that**
15 said first set of fiber property parameters is substantially the same as said second set of fiber property parameters.

11. Optical amplifier device according to any of the claims 1 to 10, **characterized in that** said first wavelength interval covers at least a part of a
20 signal band (102) of said parametric amplification of said first nonlinear optical fiber (12A-C).

12. Optical amplifier device according to any of the claims 1 to 11, **characterized in that** said second wavelength interval covers at least a part of an
25 idler band (104) of said parametric amplification of said second nonlinear optical fiber (12A-C).

13. Optical amplifier device according to any of the claims 1 to 12, **characterized by** at least one further optical fiber (12A-C) connected between

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said optical demultiplexer (14) and said optical multiplexer (16), whereby each optical fiber (12A-C) receives optical signals within a respective wavelength interval ($\Delta\lambda_1 - \Delta\lambda_8$) from said optical demultiplexer (14).

5   14.   Optical amplifier device according to claim 13, **characterized in that** at least one of said at least one further optical fiber (12C) is provided with a non-parametric amplification (19).

       15.   Optical amplifier device according to any of the claims 1 to 14,
10   **characterized in that** at least one of said nonlinear optical fibers (12A-C) has a fourth order dispersion coefficient β_4, adapted to give a flat gain band within the associated wavelength interval ($\Delta\lambda_1 - \Delta\lambda_8$).

       16.   Optical amplifier device according to any of the claims 1 to 15,
15   **characterized in that** said first and second nonlinear optical fibers (12A-C) have non-linearity coefficients γ exceeding $10 \text{ km}^{-1}\text{W}^{-1}$.

       17.   Fiber-optical communication system, comprising an optical amplifier device (1) according to any of the claims 1 to 16.

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       18.   Fiber-optical communication system according to claim 17, **characterized in that** said fiber optical system is arranged to use wavelength division multiplexing.

25   19.   Fiber-optical communication system according to claim 18, **characterized in that** said fiber optical system is arranged to use dense wavelength division multiplexing.

       20.   Method for optical amplifying, comprising the steps of:

directing (202) optical signals within a first wavelength interval $(\Delta\lambda_1-\Delta\lambda_8)$ to a first nonlinear optical fiber (12A-C);

directing (204) optical signals within a second wavelength interval $(\Delta\lambda_1-\Delta\lambda_8)$ to a second nonlinear optical fiber (12A-C);

performing (206) first parametric amplification in said first nonlinear optical fiber (12A-C), by pumping with radiation of a first pump wavelength (λ_P);

performing (208) second parametric amplification in said second nonlinear optical fiber (12A-C), by pumping with radiation of a second pump wavelength (λ_P);

said first pump wavelength (λ_P) being positioned outside said first wavelength interval $(\Delta\lambda_1-\Delta\lambda_8)$ and said second pump wavelength (λ_P) being positioned outside said second wavelength interval $(\Delta\lambda_1-\Delta\lambda_8)$; and

multiplexing (210) amplified signals from said first and second nonlinear optical fibers (12A-C).

21.　　Method according to claim 20, **characterized in that** said first wavelength interval $(\Delta\lambda_1-\Delta\lambda_8)$ being positioned at a high-gain portion of a gain distribution (100; 120, 122, 124; 126, 128, 130; 132, 134) of said first parametric amplification and said second wavelength interval $(\Delta\lambda_1-\Delta\lambda_8)$ being positioned at a high-gain portion of a gain distribution (100; 120, 122, 124; 126, 128, 130; 132, 134) of said second parametric amplification.

22.　　Method according to claim 20 or 21, **characterized by** the step of pumping said first nonlinear optical fiber (12A-C) and said second nonlinear optical fiber (12A-C) with optical signals having substantially the same wavelength.

23.　　Method according to claim 22, **characterized by** the step of pumping said first nonlinear optical fiber (12A-C) with a first optical signal and pumping

said first nonlinear optical fiber (12A-C) with a second optical signal having a wavelength different from the wavelength of said first optical signal.

24. Method according to any of the claims 20 to 23, **characterized in that** said first wavelength interval $(\Delta\lambda_1 - \Delta\lambda_8)$ covers at least a part of a signal band (102) of said parametric amplification of said first nonlinear optical fiber (12A-C).

25. Method according to any of the claims 20 to 24, **characterized in that** said second wavelength interval $(\Delta\lambda_1 - \Delta\lambda_8)$ covers at least a part of an idler band (104) of said parametric amplification of said second nonlinear optical fiber (12A-C).